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Cost Risk Analysis "For the Masses"

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17 June 2004

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Why Would You Care About this Presentation

- **Who are the "masses"?**
  - You and I, the practitioners who apply and deliver products based upon what the theorists discuss.
- **What is the message?**
  - How to apply cost risk theory in an understandable, reliable and defendable process to produce results that can be briefed with confidence.
  - Demonstrate that Crystal Ball, @RISK and ACE RI$K risk tools give the same results for the same problem.

Outline

- **Setting the Stage**
- **Six Step Cost Risk Analysis Approach**
  (with recommended decisions to be made and suggestions)
- **Concluding Observations**
- **Comparing Risk Results From Various Tools**

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Setting the Stage

Observations on Risk Analysis Case Studies

- **Essential to use a realistic cost model**

- **Too often, risk case study presentations:**
  - Roll up a few numbers, often of similar magnitude
  - Ignore phasing, inflation, learning, functional relationships, etc
  - Contain no cost estimating relationships (CERs)
  - Ignore Technical/Schedule cost risk impacts
  - Ignore the impact of correlating CER inputs
  - Ignore the presence of functional correlation
  - Ignore the fact that cost modeling needs to be efficient
  - Focus on some esoteric statistical nuance that on its own, may seem important, but in the context of an estimate…just noise.
  - Give little insight on how to apply the message in the program office environment

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Cost Risk Analysis Publications

- Risk Management Policies from DoD 5000.4-M Cost Analysis Guidance and Procedures
  http://acc.dau.mil/simplify/ev.php?ID=6388_201&ID2=DO_TOPIC
- Department of the Army Cost Analysis Manual May 2002
  http://www.ceac.army.mil/ce/default.asp
- (Air Force) Cost Analysis Guidance And Procedures 1 October 1997
  http://www.saffm.hq.af.mil/afcaa/
- NASA Cost Estimating Handbook 2002
  http://www.jsc.nasa.gov/bu2/NCEH/
  http://www.jsc.nasa.gov/bu2/conferences/NCAS2004/index.htm
- FAA Life Cycle Cost Estimating Handbook v2 03 Jun 2002
  http://www.faa.gov/asd/ia-or/lccehb.htm
- Parametric Estimating Initiative (PEI) Parametric Estimating Handbook Spring 1999
  http://www.ispa-cost.org/PEIWeb/newbook.htm

Guidance that is Tough to Implement

- "Areas of cost estimating uncertainty will be identified and quantified."
- "Areas of uncertainty, such as pending negotiations, concurrency, schedule risk, performance requirements that are not yet firm, appropriateness of analogous systems, level of knowledge about support concepts, critical assumptions, etc., *should* be presented."
- "Uncertainty will be quantified by the use of probability distributions or ranges of cost."
- "Detailed back-up material will be provided."
- "Experts disagree on the sources of uncertainty in systems acquisition."

Common Cost Risk Analyst Observations

Analysts want…

- **Clear guidance on how to conduct cost risk analysis**
- **Standard expectations for quality and completeness**
- **Consistent approaches for:**
  - Interpreting the point estimate CER (mean?, median? mode?, other?)
  - Sensitivity analysis vs. stochastic analysis?
  - Selecting a distribution and its bounds? Are there defaults?
  - Defining dispersion and/or correlation
  - Adjusting risk for schedule/technical concerns?
  - Planned growth (i.e., weight, power, operational profile, etc margins).
  - Risk allocation
  - BY vs. TY presentation

Analysts want to improve the quality of their risk adjusted cost estimates in a more productive/repeatable way.

...We've All Been There

- Given: lack of clear direction, widely different interpretations of terms and methods, mysterious high order math, "process" stakeholders lurking in the wings, etc, etc…
- The only possible result:

Detailed cost risk analysis based on "best guess" of what management wanted.

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Six Step Cost Risk Analysis Approach

Definitions and Sources of Cost Risk and Cost Uncertainty

- **Risk** **stems from a *known* probability distribution**
  - Cost estimating methodology risk
  - Cost factors such as inflation, labor rates, labor rate burdens, etc
  - Configuration risk (variation in the technical inputs)
  - Schedule and technical risk
  - Correlation between risk distributions

- **Uncertainty** **stems from an *unknown* probability distribution**
  - Potential for massive requirements changes
  - Budget Perturbations, Congressional actions
  - Re-work, and re-test phenomena
  - Contractual arrangements (contract type, prime/sub relationships, etc)
  - Potential for disaster (labor troubles, shuttle loss, satellite “falls over”, war, etc)
  - Probability that if a discrete event occurs it will invoke a project cost
  - **NOT** the subject of this paper

Cost Risk Analysis Approach

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Step 1: Create the Point Estimate

Step 2: Specify Risk

- a.) CERs & Throughputs **(Cost Risk)**
- b.) Inputs **(Configuration Risk)**
- c.) **Schedule/Technical** Considerations
- d.) **Measure** correlation in the model
  Apply additional correlation as required
- e.) **Review** assumptions for consistency

Step 3: Run the Simulation

Step 4: View & Interpret Results

Step 5: Allocate Risk

Step 6: Create BY/TY Charts

Step 1: The Point Estimate

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WBS/CES Description	Appropriation	Unique ID	BASELINE	Equation / Throughput	Fiscal Year	Units
* Base Year of Calculation			2004			
* Units of Calculation			K			
Total			$ 113,076 *			
R&D		R&D$	$ 24,141 *			
Software Development			$ 23,457 *			
Equip Software	3600		$ 1,570 *	MM$*MMEquip		
Control Sys Software	3600		$ 21,887 *	MM$*MMControl		
RD Other	3600		$ 684 *	675	2003	$K
Procurement		Proc$	$ 56,633 *			
Manufacturing		Manuf$	$ 41,543 *			
Non Recurring	3020		$ 506 *	500	2003	$K
Recurring			$ 41,037 *			
Missile	3020		$ 23,607 *	64.59 * Wgt ^ 0.7649	1992	$K
Antenna	3020	Ant$	$ 15,156 *	0.3808 * Aper ^ 1.244	1992	$K
Integration	3020		$ 2,273 *	0.15*Ant$		
SE/PM	3020		$ 10,024 *	0.2413 * Manuf$	1992	$K
Other	3020		$ 5,065 *	5000	2003	$K
O&S			$ 32,302 *			
Personnel	3500	PersTot$	$ 9,568 *	Pers * Pers$		
Maintenance	3400	Maint$	$ 22,734 *	MaintFact*AvUnit$*FieldingQty		
***INPUT VARIABLES**		*IN_VAR				
Lines of Code Equip		KLOCEquip	400.0 *	400		
NCSI Equip		NCSCIEquip	3.0 *	3		
Manmonths Equip (Non Line		MMEquip	155.0 *	1.822 * KLOCEquip ^ 0.6539 * NCSCIEquip ^ 0.4784		
Lines of Code Control		KLOC	350.0 *	350		
NCSI Control		NCSCI	3.0 *	3		
Manmonths Control System (		MMControl	2,160.6 *	17.44 * KLOC ^ 0.8284 * NCSCI ^ (-0.03033)		
Cost of Software Manmonth	3020	MM$	$ 10.130 *	10000	2003	$
Antenna Aperture (sq ft)		Aper	200.0 *	200		
Buy Quantity		BuyQty	75.0 *	FYISLIDE(DATEYR(EndR&DDate)+1)		
Antenna Lrning Slope		Slp	90.0 *	90		

Elements of a Point Estimate:

- R&D, Procurement, and O&S
- Software, Hardware & Personnel
- Inherent levels of indenture
- Combination of methods:
  - Engineering build-ups
  - Linear/non-linear CERs
  - Pass-throughs, etc.
- CERs derived from historical data
- CERs (Judgmental)
- Inflation, learning, fee/overhead
- Phased & non-phased variables
- BY & TY phased results

Decision Required: Define what should be addressed in a **risk analysis** (vs. sensitivity analysis).

Step 2: Specify the Risk

Straight-forward sequence to address the cost risk:

a) Apply risk to CERs, analogies, etc. (**Cost Estimating Risk**)

b) Apply risk to CER inputs (**Configuration Risk**)

c) Adjust for **schedule/technical** considerations (Know CER data sources)

d) **Correlate** inputs, **measure** model correlation, **determine** if more is necessary

e) **Review** risk assumptions for consistency

Step 2.a: Cost Estimating Risk: Picking a Distribution Shape

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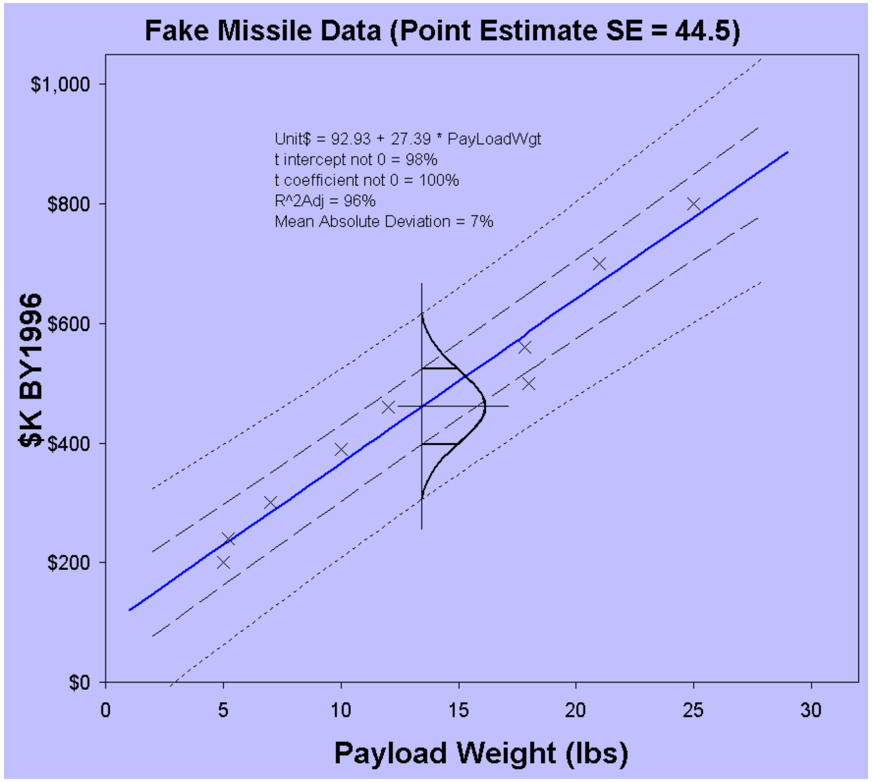
Objective Distribution Selection

- OLS CERs – produce the “**mean**” (also the mode/median), error is **normally** distributed.
- Log Space OLS CERs - produce the “**median**”, error is **log-normal** in unit space.
- MUPE CERs usually produce the “**mean**”, where error is **normally** distributed.

Subjective Distribution Selection

- Analysts will often declare that risk will be non-symmetrical about the CER result regardless of the regression method.
- Risk on non-parametric CERs (analogy, build-up, through-put, labor rates) are almost always subjective.
- Log-normal, weibull, or beta are popular to avoid a sharp peakness around the mode and to have skew with at least some probability of a large overrun.



Suggestion:
- Publish the objective distribution shape for each regression technique.
- Define how to interpret the CER (mean or median).
- Provide guidance on what to pick if there is a basis to depart from the objective shapes.

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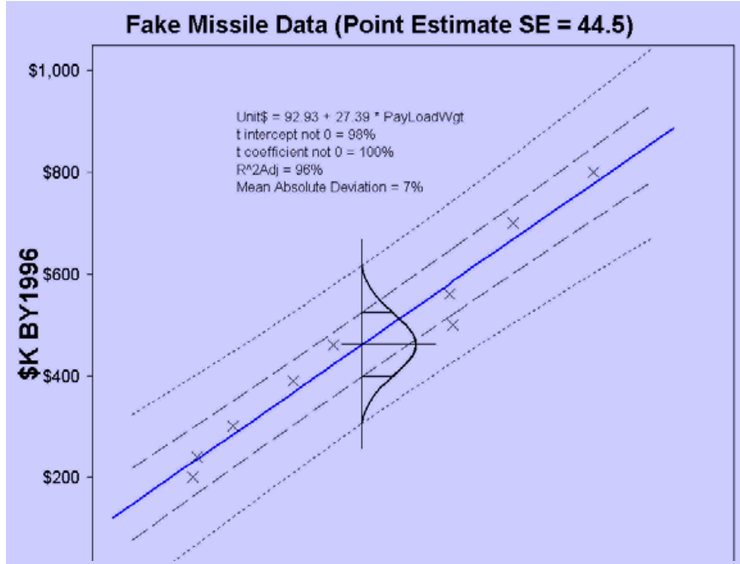
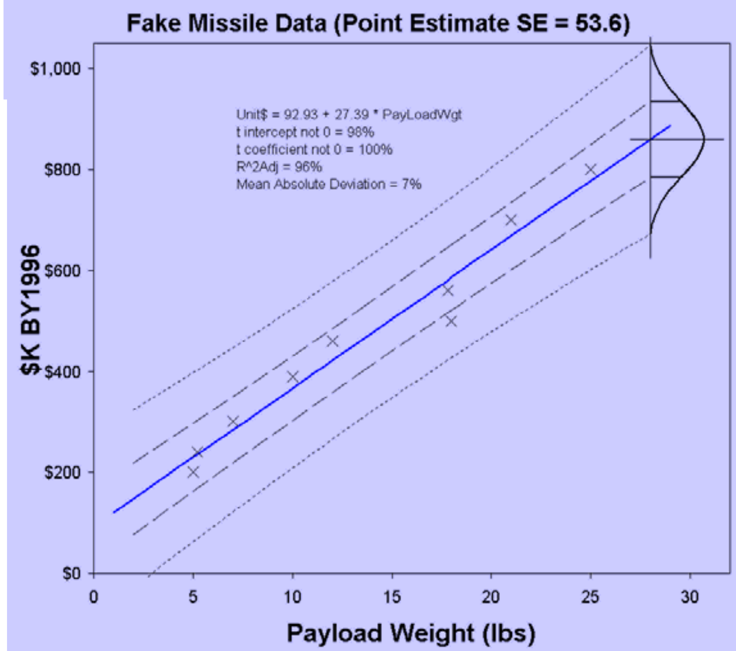
Step 2.a: Cost Estimating Risk: Selecting Distribution Bounds

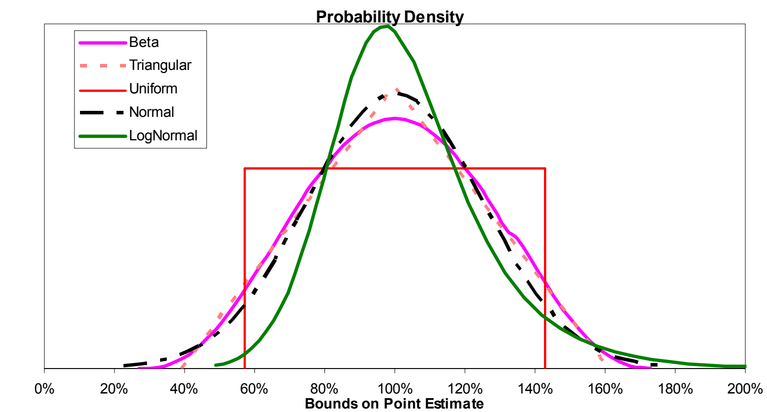
- **Statistics Available:** Prediction interval defines point estimate error bounds for a given confidence level:
  - Function of standard error, sample size, confidence, and “distance” to data center
  - Broadens away from the data center
  - Usually not reported

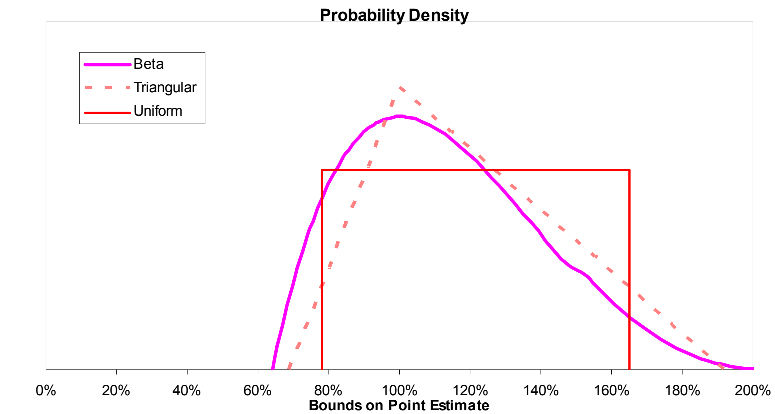
- **No Statistics Available:**
  - Guidelines are required to help users pick distribution shape and bounds
  - Numerous ad hoc processes…

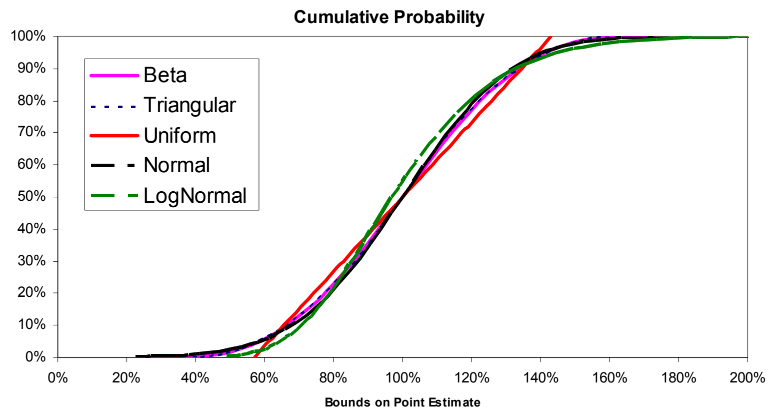


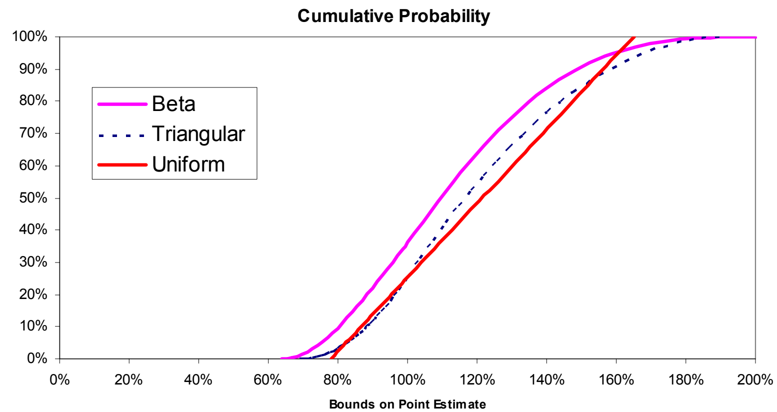


Step 2.a: "Standard" Distribution Shapes and Bounds









- **Plots compare different distribution shapes based on similar dispersion**

Suggestion:
- Publish "standard" distribution shapes and bounds.
- Develop tables for different distribution shapes by commodity.

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Step 2.b: Configuration Risk

- **Focus is now on the inputs (risk or sensitivity analysis?)**
- **Frequent sources of cost risk: learning slope, lines of code count, antenna aperture size, etc. assumptions.**
- **Modeling considerations:**
  - Do CER inputs represent design goals or include allowable margin?
  - Do CER inputs represent the mode/mean/median (normal error) or median (log-normal error) or some other percentile value?
  - Are only discrete sets of CER inputs permissible (i.e. is it inappropriate to model them with continuous risk distributions)?
  - Can CER inputs be functionally linked? For instance, can airframe weight be estimated from the engine weight?

Suggestion: Publish “default” input variable interpretation, distribution shapes, and bounds based upon commodity type.

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Step 2.c: Schedule/Technical Considerations

- Difficult to isolate schedule from technical cost impacts. Many approaches assess the impact together (see paper for details).
- Compare the project you are estimating to the CER source data.
- CERs, estimating methods, analogy and expert opinion estimating processes are influenced by past, real projects.
- Estimating methods capture some "nominal" schedule/technical cost impact (contributes to OLS error term?).
- Realistically assess the degree to which the schedule and technical considerations relate to the CER source.
- Subjective assessment.

Decision Required:

- Default method for adjusting risk distributions to capture schedule and technical considerations:
  - Penalty factor on the distribution high bound.
  - Introduce an additional distribution .
  - Other methods available.

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Step 2.d: Correlation

- **Focus attention on the <u>input variables first</u>.**
- **Modeling considerations often overlooked when trying to assess the correlation <u>*already present*</u> in the cost model**
  - Functional relationships between the input variables.
  - Functional relationships between WBS elements.
  - More than one CER sharing same risk-adjusted input variable. (Most common: learning slope).
  - Same CER used in multiple places in the cost model.
  - Same phased buy quantity applied to multiple cost elements.
- **<u>*Measure*</u> to determine if more correlation is required.**

Unintentional Correlation?

	WBS/CES Description	BASELINE	Unique ID	Equation / Throughput	Curve Slope	Distribution Form	Low or Low %	High or High %	Spread	Skew
44	Procurement	$ 56,633 (26%) *	Proc$							
45	Manufacturing	$ 41,543 (30%) *	Manuf$							
46	Non Recurring	$ 506 (23%) *		500		Uniform	80%	200%		
47	Recurring	$ 41,037 (30%) *								
48	Missile	$ 23,607 (37%) *		64.59 * Wgt ^ 0.7649	AntSlp	LogNormal	87.29%	114.56%		
49	Antenna	$ 15,156 (29%) *	Ant$	0.3808 * Aper ^ 1.244	AntSlp	LogNormal	85.5%	116.9%		
50	Integration	$ 2,273 (26%) *		0.15*Ant$		Beta			Medium	Right
51	SE/PM	$ 10,024 (37%) *		0.2413 * Manuf$		Normal	54.2%	145.8%		
52	Other	$ 5,065 (10%) *		5000		Triangular	100%	200%		
57										
59	Antenna Lrning Slope	90.0 (37%) *	AntSlp	90		Uniform	85	100		

Same risk adjusted slope variable for missile/antenna.

	WBS/CES	Row 37: Total	Row 44: Procu	Row 45: Manu	Row 47: Recu	Row 48: Missile	Row 49: Anten	Row 50: Integr	Row 51: SE/PM	80.0% Level
37	Total	1.00	0.90	0.90	0.90	0.68	0.88	0.79	0.68	$ 177,979.07
44	Procurement		1.00	0.97	0.97	0.83	0.88	0.79	0.80	$ 91,714.58
45	Manufacturing			1.00	1.00	0.85	0.91	0.81	0.66	$ 67,666.46
47	Recurring				1.00	0.85	0.91	0.81	0.66	$ 66,884.04
48	Missile					1.00	0.56	0.48	0.56	$ 35,638.72
49	Antenna						1.00	0.87	0.60	$ 28,166.22
50	Integration							1.00	0.54	$ 4,798.61
51	SE/PM								1.00	$ 17,645.23

- **Much worry over possible *underestimated* correlation**
- **No apparent concern over possible *excessive* correlation**

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Removing Unintentional Correlation

	WBS/CES Description	BASELINE	Unique ID	Equation / Throughput	Curve Slope	Distribution Form	Low or Low %	High or High %	Spread	Skew
44	Procurement	$ 56,633 (18%) *	Proc$							
45	Manufacturing	$ 41,543 (21%) *	Manuf$							
46	Non Recurring	$ 506 (23%) *		500		Uniform	80%	200%		
47	Recurring	$ 41,037 (22%) *								
48	Missile	$ 23,607 (37%) *		64.59 * Wgt ^ 0.7649	MissSlp	LogNormal	87.29%	114.56%		
49	Antenna	$ 15,156 (29%) *	Ant$	0.3808 * Aper ^ 1.244	AntSlp	LogNormal	85.5%	116.9%		
50	Integration	$ 2,273 (26%) *		0.15*Ant$		Beta			Medium	Right
51	SE/PM	$ 10,024 (34%) *		0.2413 * Manuf$		Normal	54.2%	145.8%		
52	Other	$ 5,065 (10%) *		5000		Triangular	100%	200%		
57										
59	Antenna Lrning Slope	90.0 (37%) *	AntSlp	90		Uniform	85	100		
60	Missile Lrning Slope	90.0 (37%) *	MissSlp	90		Uniform	85	100		

Need separate slope variable for the missile.

- Missile/ Antenna correlation now 0.
- Rec cost is now 5% less.

	WBS/CES	Row 37: Total	Row 44: Procu	Row 45: Manuf	Row 47: Recur	Row 48: Missile	Row 49: Anten	Row 50: Integr	Row 51: SE/PM	80.0% Level
37	Total	1.00	0.86	0.85	0.85	0.33	0.82	0.73	0.61	$ 173,903.81
44	Procurement		1.00	0.96	0.96	0.59	0.75	0.68	0.77	$ 87,848.49
45	Manufacturing			1.00	1.00	0.62	0.78	0.71	0.58	$ 64,449.32
47	Recurring				1.00	0.62	0.78	0.71	0.58	$ 63,686.82
48	Missile					1.00	0.00	-0.01	0.36	$ 35,457.46
49	Antenna						1.00	0.87	0.46	$ 28,166.22
50	Integration							1.00	0.42	$ 4,798.61
51	SE/PM								1.00	$ 17,298.13

Decisions Required:
Define Correlation Strength
- Strong (.9?)
- Moderate (.6?)
- Weak (.2?)

When to apply?

Step 2.e Review for Consistency

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	WBS/CES Description	BASELINE	Unique ID	Equation / Throughput	Distribution Form	Low or Low %	Low Interpr	High or High %	High Interpr	Spread	Skew	LogNormal	Schedule/ Technolog	Grouping	Group Strengt	Random Seed
37	Total	$ 113,076 (13%) *	Total$													
38	R&D	$ 24,141 (33%) *	R&D$													
39	Software Develop	$ 23,457 (34%) *														
40	Equip Software	$ 1,570 (23%) *		MM$*MMEquip												
41	Control Sys Sof	$ 21,887 (35%) *		MM$*MMControl												
42	RD Other	$ 684 (10%) *		675	Uniform	100%	10	167%	90					TP	.95	7343
43																
44	Procurement	$ 56,633 (18%) *	Proc$													
45	Manufacturing	$ 41,543 (21%) *	Manuf$													
46	Non Recurring	$ 506 (23%) *		500	Uniform	80%	10	200%	90					TP	0.95	24737
47	Recurring	$ 41,037 (22%) *														
48	Missile	$ 23,607 (37%) *		64.59 * Wgt ^ 0.7649	LogNormal	87.29%	10	114.56%	90							20950
49	Antenna	$ 15,156 (29%) *	Ant$	0.3808 * Aper ^ 1.244	LogNormal	85.5%	10	116.9%	90				2.07			7584
50	Integration	$ 2,273 (26%) *		0.15*Ant$	Beta					Medium	Right					5729
51	SE/PM	$ 10,024 (34%) *		0.2413 * Manuf$	Normal	54.2%	10	145.8%	90							19164
52	Other	$ 5,065 (10%) *		5000	Triangular	100%	10	200%	90					TP	0.95	4041
57																
58	***INPUT VARIABLE!**		*IN_VAR													
59																
60	Lines of Code Equip	400.0 (10%) *	.OCEquip	400	Triangular	100%	10	150%	95					TP	0.95	7742
61	NCSI Equip	3.0 *	SCIEquip	3												
62	Manmonths Equip (Nor	155.0 (27%) *	MMEquip	1.822 * KLOCEquip ^	LogNormal							.16		R&D	.95	31517
63																
64	Lines of Code Control	350.0 (10%) *	KLOC	350	Triangular	100%	10	150%	95					TP	0.95	779
65	NCSI Control	3.0 *	NCSCI	3												
66	Manmonths Control Sys	2,160.6 (38%) *	MControl	17.44 * KLOC ^ 0.8284	LogNormal	58%	10	172%	90					R&D	.95	31045
67	Cost of Software Manm	$ 10.130 (32%) *	MM$	10000	Triangular	95%	10	115%	90							30708
68																
69	Antenna Lrning Slope	90.0 (37%) *	AntSlp	90	Uniform	85	10	100	90							4387
70	Missile Lrning Slope	90.0 (37%) *	MissSlp	90	Uniform	85	10	100	90							22125
71	Antenna Aperture (sq ft	200.0 (43%) *	Aper													5

Bounds expressed as % of point estimate are:

- Easier to understand
- Scale with changes to the point estimate
- Provide a consistent basis for comparison

Step 3: Run the Simulation

- **Simulation tool results are influenced by:**
  - Truncation assumption
  - Number of iterations
  - If using Latin Hypercube [LHC], the number of partitions
  - Random seed

- **When properly applied, ACEIT, Crystal Ball, @Risk and FRisk all produce similar results.**

Decision Required:
- Identify acceptable risk simulation tools
- Provide guidance on how they should be applied

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Step 4: View and Interpret Results

	WBS/CES	Point Estimate	Mean	Std Dev	CoV	5.0% Level	20.0% Level	50.0% Level	80.0% Level	95.0% Level
37	Total	$ 113,076 (21%)	$ 150,191	$ 45,872	0.305	$ 88,364	$ 111,895	$ 142,650	$ 185,628	$ 234,738
38	R&D	$ 24,141 (33%)	$ 31,933	$ 14,560	0.456	$ 14,706	$ 20,355	$ 28,905	$ 41,378	$ 59,602
39	Software Development	$ 23,457 (34%)	$ 31,021	$ 14,518	0.468	$ 13,876	$ 19,521	$ 28,022	$ 40,416	$ 58,642
40	Equip Software	$ 1,570 (24%)	$ 1,864	$ 397	0.213	$ 1,301	$ 1,524	$ 1,821	$ 2,174	$ 2,582
41	Control Sys Software	$ 21,887 (35%)	$ 29,157	$ 14,375	0.493	$ 12,143	$ 17,750	$ 26,159	$ 38,459	$ 56,547
42	RD Other	$ 684 (10%)	$ 913	$ 165	0.181	$ 655	$ 741	$ 913	$ 1,085	$ 1,171
43										
44	Procurement	$ 56,633 (24%)	$ 74,400	$ 23,358	0.314	$ 42,478	$ 54,201	$ 71,194	$ 92,722	$ 117,351
45	Manufacturing	$ 41,543 (27%)	$ 53,859	$ 17,480	0.325	$ 29,576	$ 38,364	$ 51,449	$ 67,768	$ 86,195

- **Risk analysis will give context to the point estimate**
- **CoV (Stdev/Mean) and confidence of the point estimate (PEcl) are useful measures of the overall risk in the cost model.**
- **Observations:**
  - Estimates rich in parametric CERs: 15%<CoV<45%, and 5%<PEcl<30%
  - Estimates rich in build-up methods: 5%<CoV<15%, and 30%<PEcl<45%

Suggestion: Identify reasonable, commodity-based metrics the analyst can use to assess the completeness and possibly the quality of the risk analysis as it is being developed.

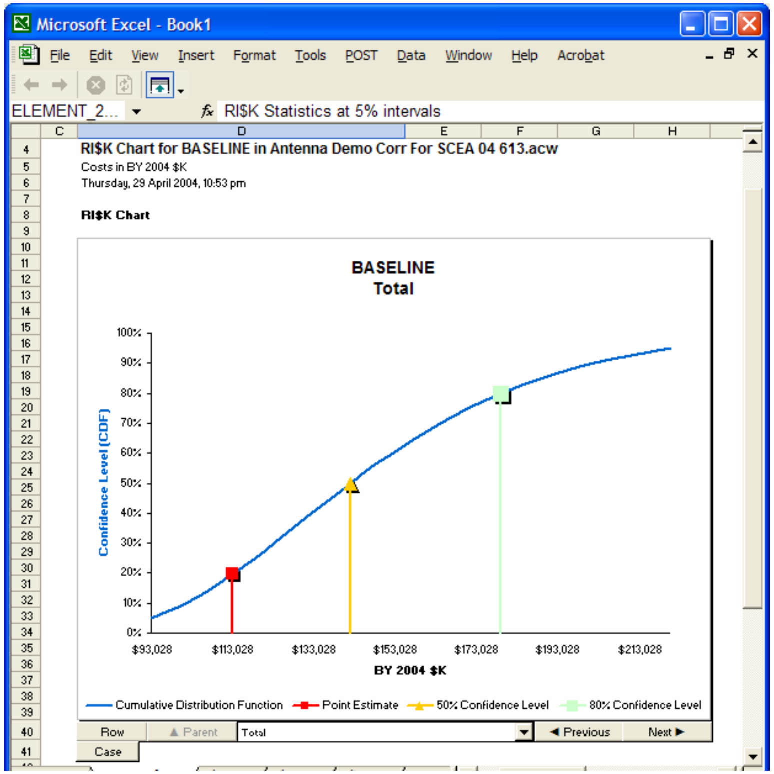
Step 5: Allocate Risk

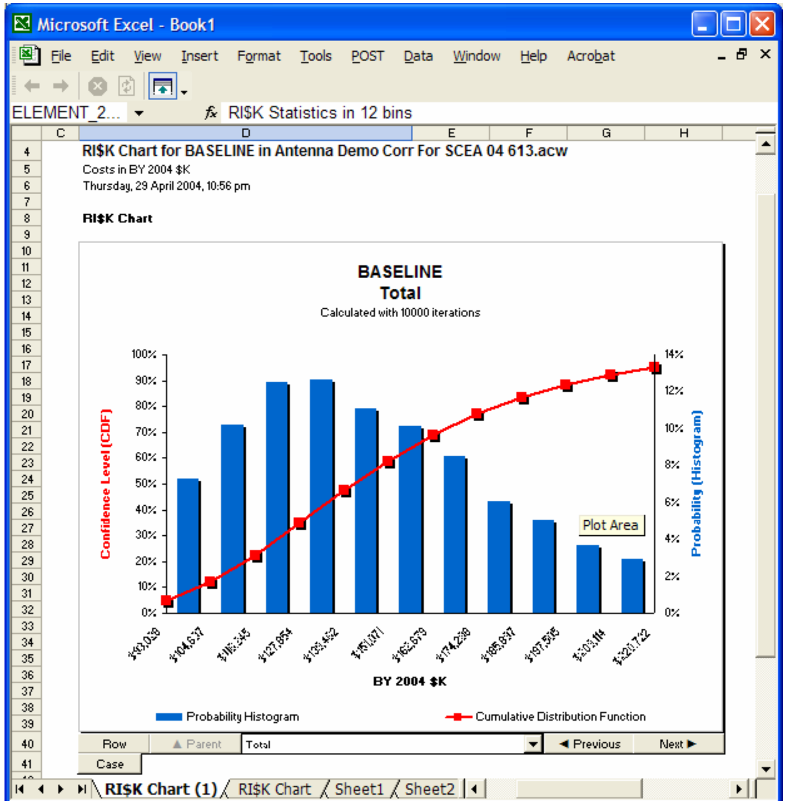
- **Confidence level results *do not add***
  - Mathematicians are quite happy with this result, budget folks are not.
- **Results must:**
  - Be phased in both BY and TY$
  - Add up
- **Significant issues must be resolved to define a phased, risk allocation method with consistent BY and TY results.**
- **Phasing assumptions will have *<u>significant impact</u>* on TY results.**

Decision Required:

- Choose the “standard” risk allocation approach, including how the cost risk dollars should be phased.
- Cost models should be flexible enough to phase the risk dollars consistent with the program managers risk mitigation plans.

Step 6: Charts and Tables





Decision Required:

- Identify the standard charts and their contents to be presented to management.
- Ensure consistent x and y-axis arrangements.
- Determine “if” a TY S-curve should be presented and if so, define the process to be used.

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Concluding Observations

Benefits of Clear Guidance

- **Default positions would establish a minimum expectation for estimates – not a cookbook**
- **No need to "over specify" the guidance**
- **Advanced analysts will still develop sophisticated models to deal with exceptional circumstances**
- **Establishing a "standard process" will:**
  - Focus attention on "building" the estimate rather than defining "how" to build it.
  - Enable more risk analysis practitioners to "do" cost risk analysis ***with confidence***.

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Compare Cost Risk Tools

Compare Cost Risk Tool Results

- **What are the risk tools and which should I choose?**
- **ACE RI$K, Crystal Ball, @Risk and FRisk *results* are compared…. Not their usability or suitability.**
- **Three case studies examined:**
  - Two are published, simple and analytically solved case studies (Reference 4 and 5).
  - Third example is based upon a more "realistic" cost model (Reference 7).
- **If handled properly, *they all produce similar total cost distribution results*.**

Case Study Page CE V – 80 SCEA Training Manual

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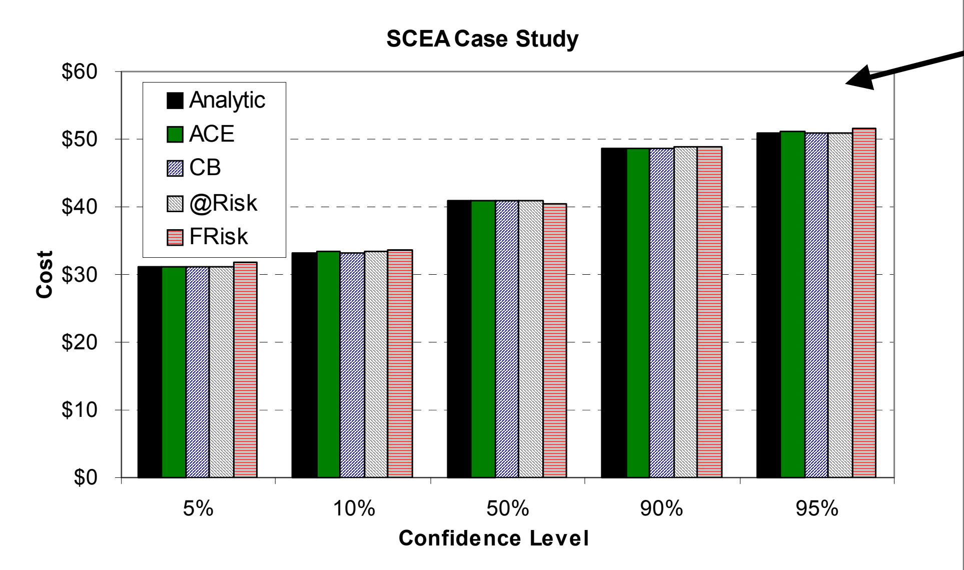
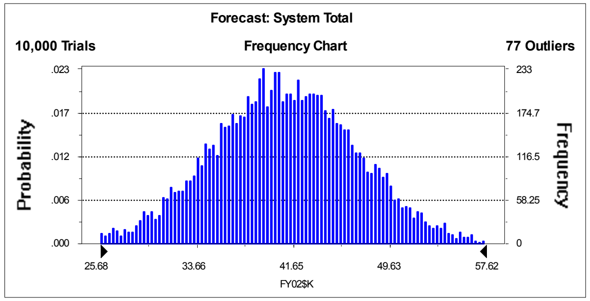
WBS	Equation/ Throughput	Distrn	Lower	Point Estimate	Upper	Analytic Stdev	ACE Stdev	CB Stdev	@Risk Stdev
Electronic System						6.015	6.013	6.026	5.998
PMP	12.50	Normal		12.500		2.569	2.570	2.569	2.569
SEPM	0.5*PMP			6.250		1.285	1.285	1.284	1.285
Sys Test & Evaluation				4.706		0.811	0.811	0.812	0.809
Sys Test & Eval	0.3125*PMP			3.906		0.803	0.803	0.803	0.803
Management Reser	0.80	Uniform	0.6	0.800	1.0	0.115	0.116	0.115	0.115
Data and Tech Orders	0.1*PMP			1.250		0.257	0.257	0.257	0.257
Site Survey & Activatio	6.60	Tiangular	5.1	6.600	12.1	1.505	1.505	1.505	1.505
Initial Spares	0.1*PMP			1.250		0.257	0.257	0.257	0.257
System Warranty	1.10	Uniform	0.9	1.100	1.3	0.115	0.116	0.115	0.115
Early Prototype Phase	1.50	Triangular	1.0	1.500	2.4	0.290	0.290	0.290	0.290
Operations Supt	1.20	Triangular	0.9	1.200	1.6	0.143	0.143	0.143	0.143
System Training	0.25*PMP			3.125		0.642	0.643	0.642	0.642

- **Combination of throughput and factor relationships**
- **No risk applied to the factors**
- **PMP drives about 70% of the model result, so 70% of the risk is modeled with a normal distribution making it reasonable that the total cost is likely to be normally distributed.**
- **Sys Test & Eval has an additive risk which is unusual in cost risk analysis. We generally assume the risk scales with the estimate.**

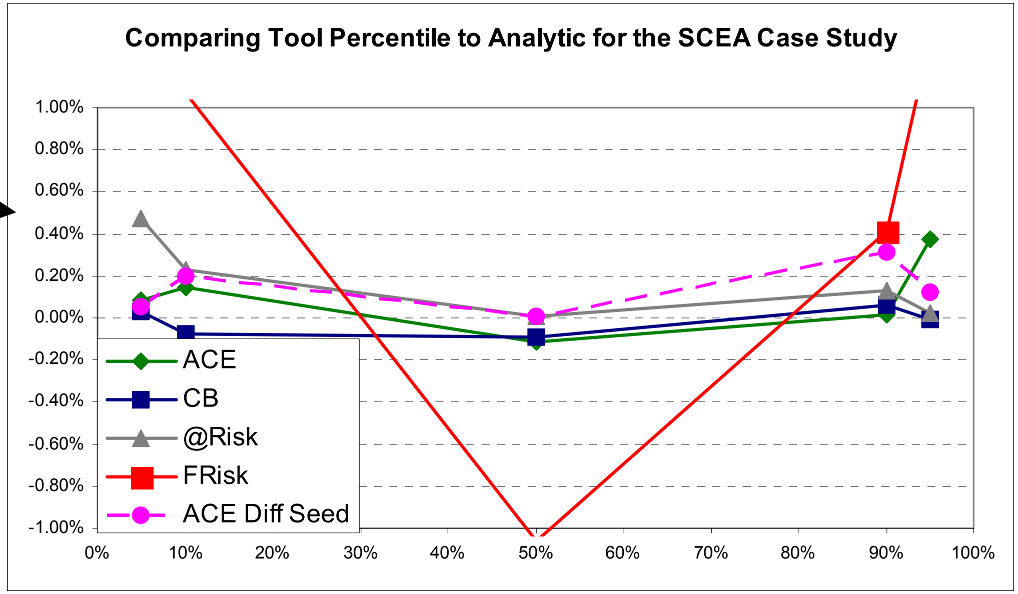
All Tools Perform Well



Use this scale if you wish to show that all models are not bad (FRisk is a little off because it assumes a log-normal distribution at the total level). Note that the simulation tool total result ***does*** appear "normal".

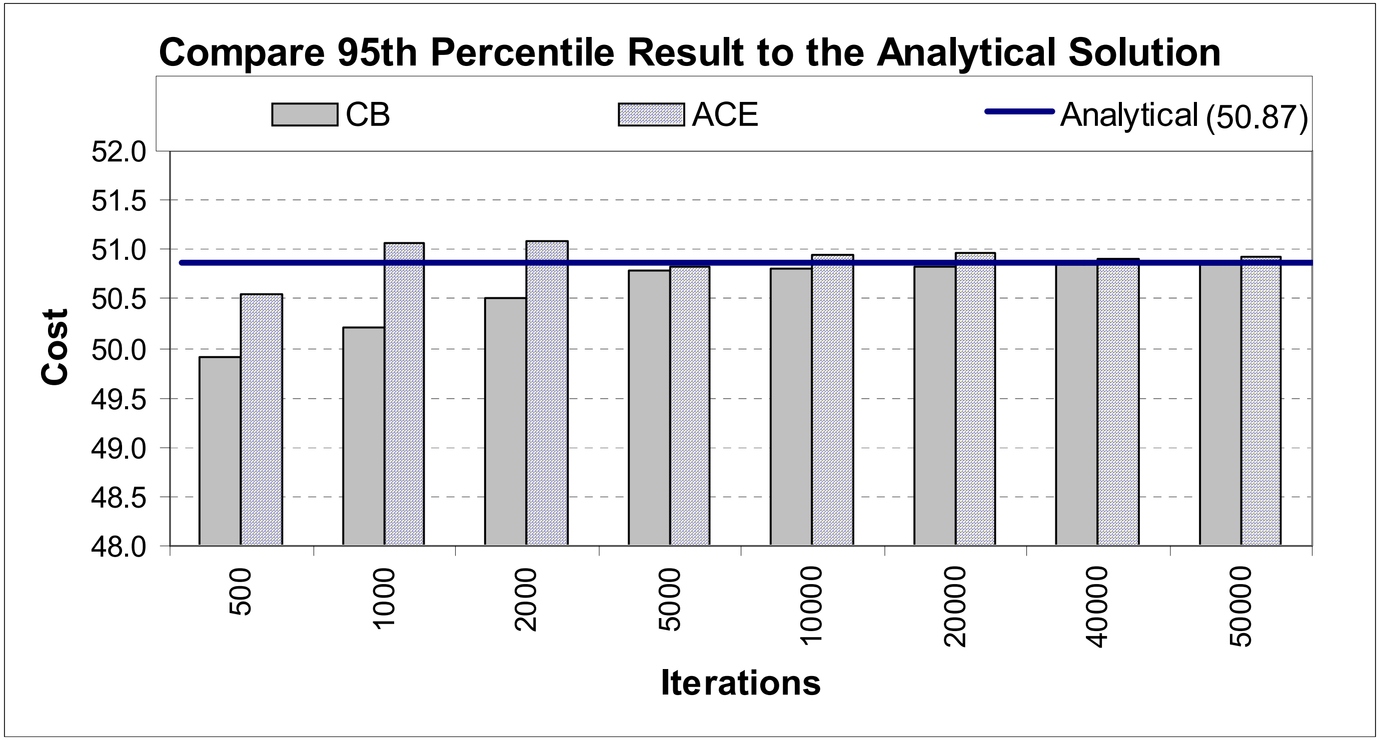


- Use this scale if you wish to show there are in fact differences amongst the models.
- However, note that the scale is so magnified, that simply changing the initial seed value (ACE is shown, but all behave the same) noticeably changes the results!



How Many Iterations Required?

- Use Latin Hypercube and maximize the number of partitions. (Crystal Ball default is 500 and max is 5000, ACE and @Risk use the same number of partitions as iterations).
- DO NOT conclude from the chart that ACE stabilizes with fewer iterations than Crystal Ball. Simply changing seed values (or LHC partition in Crystal Ball) can cause the results to "flip/flop".
- Both tools stabilize near 5000 iterations for this model.



Risk By Hand Calculator (Ref 5)

	Point Estimate	Mean	Distribution	Lower	Upper
System X	1250.000	**1,756.00**		625	3393
Antenna	380.00	574.00	Tiangular	191	1151
Electronics	192.00	290.00	Tiangular	96	582
Structure	76.00	84.00	Tiangular	33	143
LV Adaptor	18.00	18.00	Tiangular	9	27
Power Distribution	154.00	232.00	Tiangular	77	465
ACS/RCS	58.00	58.00	Tiangular	30	86
Thermal Control	22.00	33.00	Tiangular	11	66
TT&C	120.00	120.00	Tiangular	58	182
Software	230.00	347.00	Tiangular	120	691

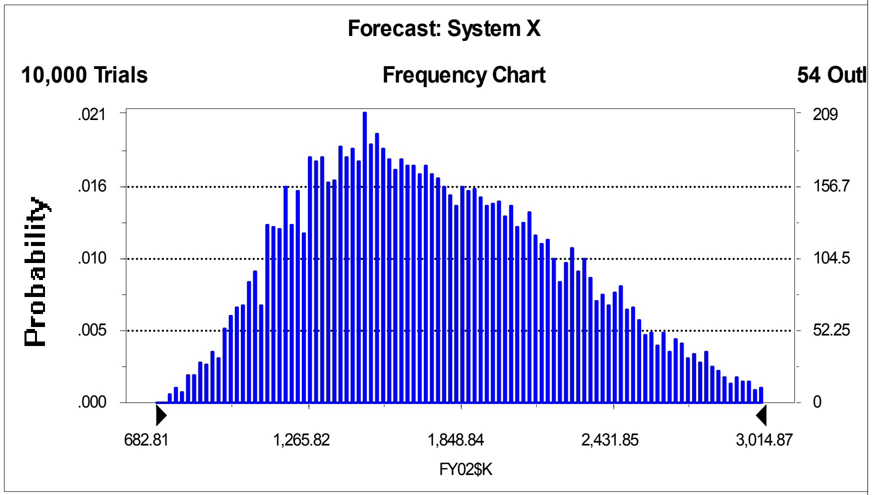
- No functional relationships.
- Triangular distributions only.
- No need to force tools to truncate distributions at "0".

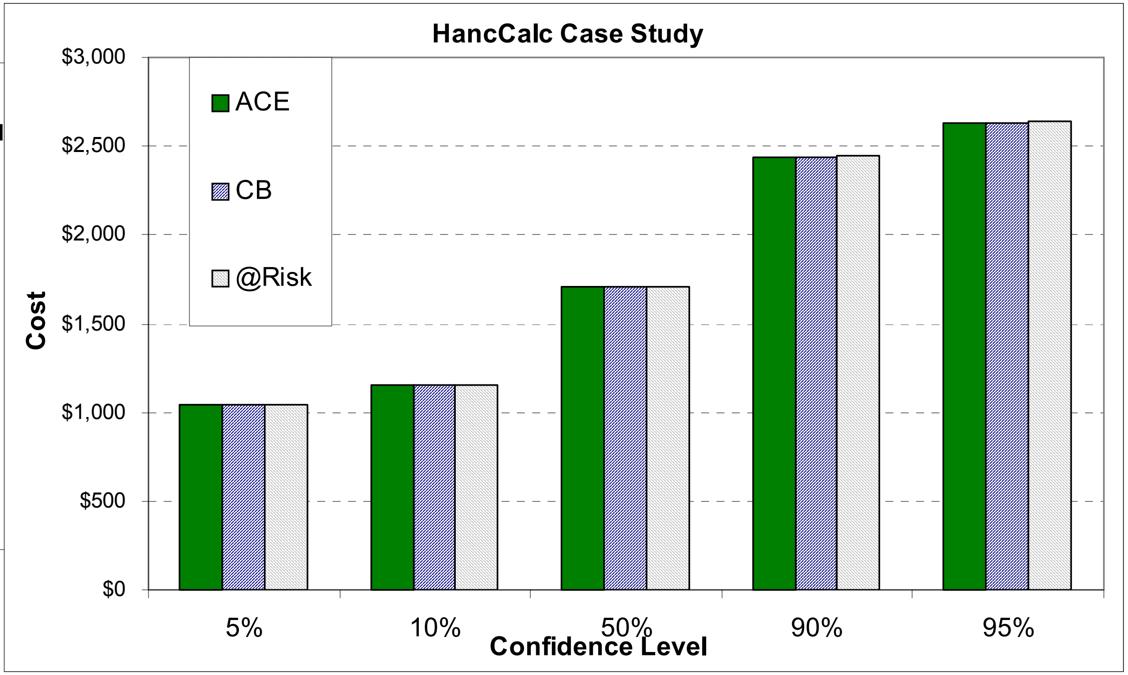
As Specified Correlation Matrix

	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	**1.0**	0.5	0.5	0.6	0.5	0.5	0.3	0.7	0.7
Electronics	0.5	**1.0**	0.4	0.5	0.5	0.6	0.5	0.5	0.7
Structure	0.5	0.4	**1.0**	0.7	0.6	0.7	0.7	0.5	0.7
LVAdaptor	0.6	0.5	0.7	**1.0**	0.4	0.4	0.5	0.3	0.6
PowDistr	0.5	0.5	0.6	0.4	**1.0**	0.5	0.5	0.5	0.7
ACSRCS	0.5	0.6	0.7	0.4	0.5	**1.0**	0.4	0.7	0.8
Thermal	0.3	0.5	0.7	0.5	0.5	0.4	**1.0**	0.5	0.7
TTC	0.7	0.5	0.5	0.3	0.5	0.7	0.5	**1.0**	0.8
Software	0.7	0.7	0.7	0.6	0.7	0.8	0.7	0.8	**1.0**
Average	0.59	0.58	0.64	0.56	0.58	0.62	0.57	0.61	0.74

- Detailed correlation matrix .
- Entered explicitly into CB & @Risk
- Pick column with highest average to enter into ACE.

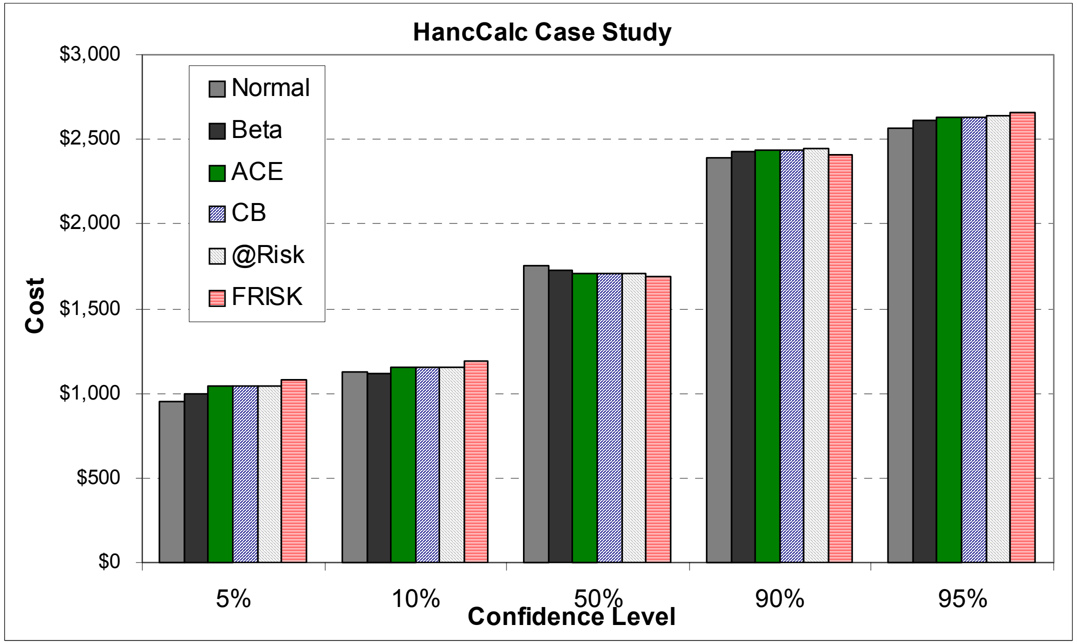
Simulation Total Cost Does Not Appear "Normal"

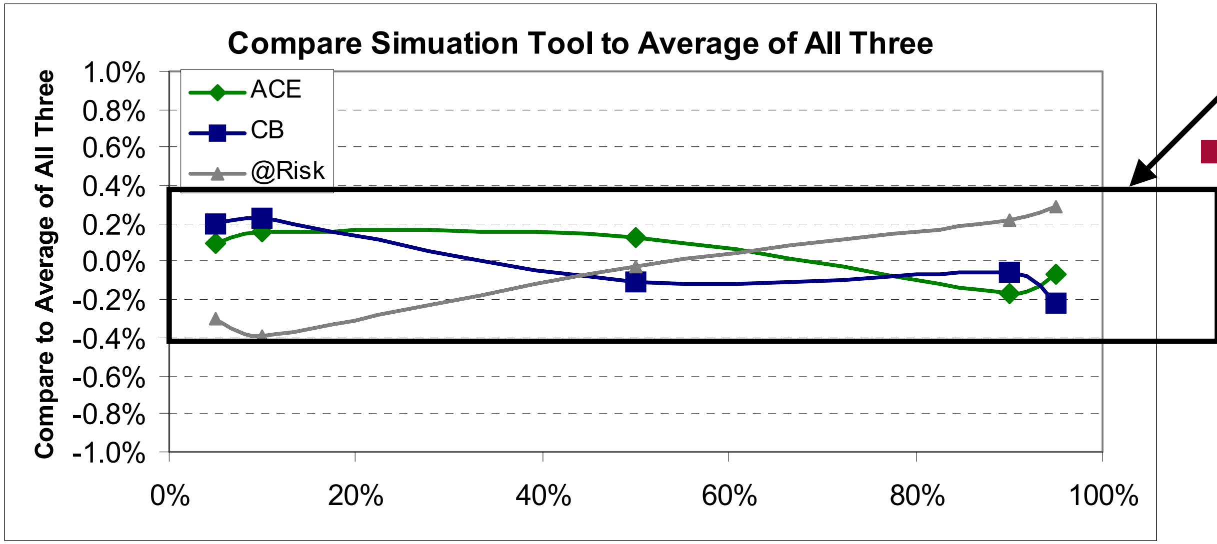




- All simulation tools match each other. Had to use bar chart rather than "S" for comparisons, otherwise impossible to discern different tool result.
- All simulation tools suggest the total cost distribution is ***not*** "normal".
- Only nine elements and with correlation layered on top, suggests that the Central Limit Theorem may not be applicable.
- With this information, we were motivated to produce analytical results based on a beta distribution.
- FRisk will provide results based upon a Log-Normal assumption.

Not Clear Which is "Right", Fortunately they are all the "*Same*"





- **Analytic based on beta distribution compares "better" to the simulation tools than "normal" or log normal (FRisk)**
- **All solutions likely well within the total cost estimate confidence**
- **Difference between simulation tools less than expected "noise" of the applications**
- **NOTE: Detailed correlation matrix was explicitly modeled in Crystal Ball and @Risk. This *did not* "improve" the result.**

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A "Realistic" Model

	B	C	D	E	H	I	K	M	N	O	P	Q	R	S	T	U
4									1000 Iterations, Latin Hyper-Cube Comparison							
5									Standard Deviation			Mean			95th Perce	
6	VBS/CES Description	Inique ID	Eqn	FY	Low	High	Risk	Simulation	CB	ACE	ACE:CB	CB	ACE	ACE:CB	CB	ACE
7	Space System NR							$480,484.07	$187,627	$188,446	0.44%	$533,747	$533,537	-0.04%	$878,571	$875,281
8	Program Management/Systems Engine	PMSE	1.487*(PLNR+SCNR)^0.841	1992	46.80%	153.20%	1	$78,844.45	$50,241	$50,417	0.35%	$89,408	$89,430	0.03%	$184,204	$184,262
9	Payload (P/L) Non Recurring	PLNR						$125,388.99	$57,295	$55,684	-2.81%	$142,375	$142,118	-0.18%	$244,566	$242,655
10	Payload IA&T							$18,766.74	$14,536	$14,180	-2.45%	$22,752	$22,658	-0.41%	$50,100	$49,210
11	Integration, Assembly, Test and Checkout (IA		850.764 + 0.159 * PLPME	1992	35.30%	164.70%	1	$17,959.81		$14,060			$21,526			$47,863
12	Software Integration		.28*PLSW	2001	80%	120%	1	$806.93		$399			$1,132			$1,882
13	Payload PME NR	PLPME						$106,622.25	$45,801	$44,542	-2.75%	$119,623	$119,461	-0.14%	$202,048	$200,056
14	Optical Telescope Assembly (OTA)							$9,517.65	$3,945	$3,975	0.75%	$9,896	$9,882	-0.14%	$16,816	$16,872
15	Structure		70.215 * OTASTRWT^0.830	1992	41.90%	158.10%	1	$6,215.42		$2,985			$6,295			$11,655
16	Electrical		256.664*OTAELECTR^0.761	1992	14.60%	185.40%	1	$3,302.23		$2,039			$3,588			$7,279
17	Pointing Subsystem							$22,887.14	$8,846	$9,063	2.45%	$24,794	$24,793	-0.01%	$40,592	$40,863
18	Scan Mirror		70.215 * SCANMIRRORSTRWT^0.830	1992	37.40%	162.60%	1	$1,121.58	$566	$565	-0.25%	$1,144	$1,145	0.08%	$2,162	$2,154
19	Gimbal							$17,103.46	$7,732	$7,888	2.02%	$18,915	$18,919	0.02%	$32,702	$32,882
20	Gimbal Structure		70.215 * GIMBALSTRWT^0.830	1992	39%	161%	1	$2,925.20		$1,461			$2,982			$5,627
21	Motor Drive Electronics		416.033+23.754*MOTORDRVPCDWT	1992	25.10%	174.90%	1	$801.62		$432			$846			$1,600
22	LOS Computer		256.878*LOSCOMPTUDEWT	1992	5.70%	194.30%	1	$6,992.34		$4,835			$7,872			$16,812
23	IMU electronics		256.878*IMUPMATUDEWT	1992	5%	195%	1	$6,384.31		$4,447			$7,220			$15,465

Compare / USCM 7 CB / @RISK Correlations / USCM 7 @Risk / REPORT (4)

Microsoft Excel - 4 USCM7 CER Risk, CER Corr, Config Risk, Config Corr CrystalBall AtRisk Apr04.xls

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Type a question for help

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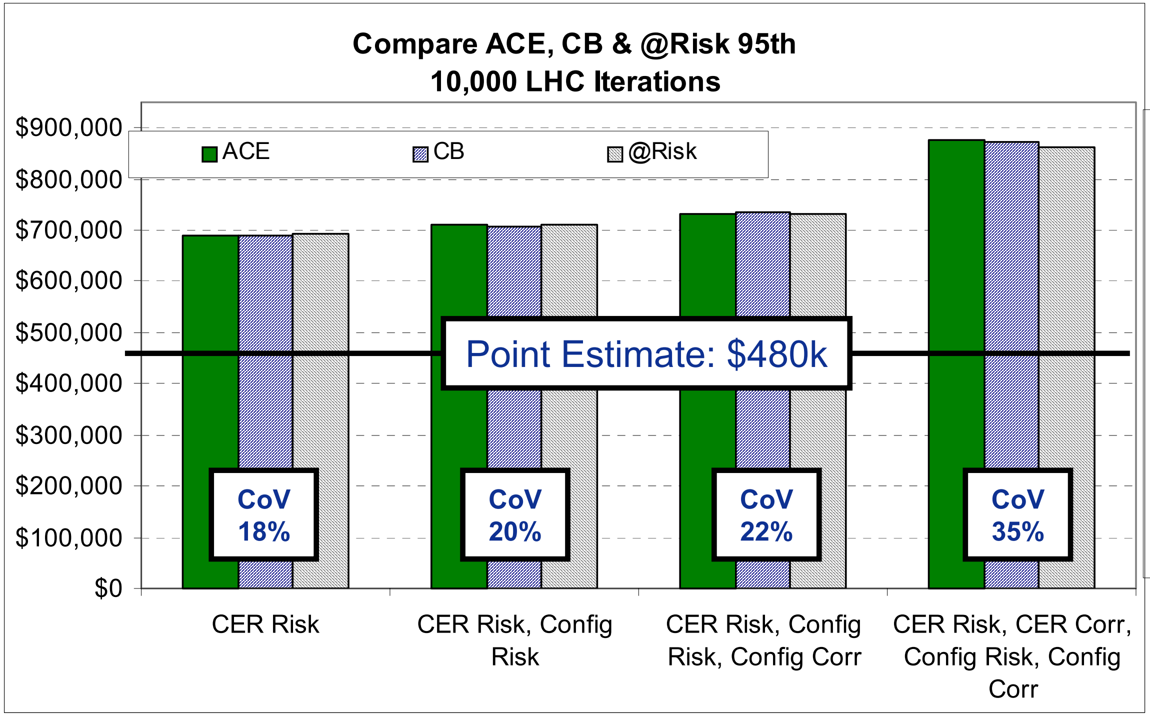
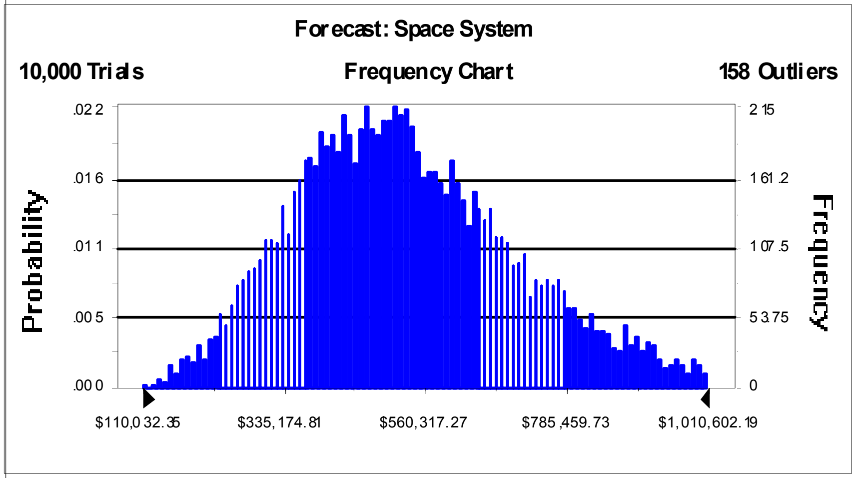
	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB
3			aPMSE	aIATC	aSoftInt	aOTStru	aOTElec	aScanM	aGimStru	aGimMDE	aGimLOSC	aGimIMU	aPayloadRel	aFPADet	aFPAAna	aSPAStru	aSPADigSig	aSPAPS	aPLSoft	aTCSAct	aTCSPass	aIATCSpace	aIATCSoft	aSpaceStrMec	aSpaceTCSAct	aSpaceTCSPass	aSpaceEPSPG	aSpaceEPSPS	aSpaceEPSPC	aSpaceEPSPC	aSpaceADCSAll
4	1	aPMSE	1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
5	2	aIATC		1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
6	3	aSoftInt			1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
7	4	aOTStru				1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
8	5	aOTElec					1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
9	6	aScanM						1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
10	7	aGimStru							1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
11	8	aGimMDE								1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
12	9	aGimLOSC									1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
13	10	aGimIMU										1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20

Compare / USCM 7 CB / @RISK Correlations / USCM 7 @Risk / REPORT (4)

USCM 7 Comparison





- More than 30 linear, non-linear, throughput CERs and 30 input values
- Compared total cost result at the 95th percentile based upon a systematic layering of correlation assumptions
- All three tools produce remarkably similar results.

Comparing Risk Tools

- **If you are consistent with:**
  - Number of iterations.
  - If using Latin Hypercube [LHC], the number of partitions.
  - Inflation, learning, and other modeled adjustments.
  - How functional correlations are modeled
  - Distribution shape and bound assumptions.
  - Truncation assumptions.
- **If you follow the tool developer's recommendation for inputting correlation:**

ACE, Crystal Ball and @Risk will give similar results.

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Backup Slides

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Example of Intentionally Correlating Independent Items

* Base Year of Calculation			2004	
* Units of Calculation			K	
Total			$ 113,076 *	
R&D		R&D$	$ 24,141 *	
Software Development			$ 23,457 *	
Equip Software	3600		$ 1,570 *	MM$*MMEquip
Control Sys Software	3600		$ 21,887 *	MM$*MMControl
RD Other	3600		$ 684 *	675
Procurement		Proc$	$ 56,633 *	
Manufacturing		Manuf$	$ 41,543 *	
Non Recurring	3020		$ 506 *	500
Recurring			$ 41,037 *	
Missile	3020		$ 23,607 *	64.59 * Wgt ^ 0.7649
Antenna	3020	Ant$	$ 15,156 *	0.3808 * Aper ^ 1.244
Integration	3020		$ 2,273 *	0.15*Ant$
SE/PM	3020		$ 10,024 *	0.2413 * Manuf$
Other	3020		$ 5,065 *	5000
O&S			$ 32,302 *	
Personnel	3500	PersTot$	$ 9,568 *	Pers * Pers$
Maintenance	3400	Maint$	$ 22,734 *	MaintFact*AvUnit$*FieldingQty
***INPUT VARIABLES**		*IN_VAR		
Lines of Code Equip		KLOCEquip	400.0 *	400
NCSI Equip		NCSCIEquip	3.0 *	3
Manmonths Equip (Non Line		MMEquip	155.0 *	1.822 * KLOCEquip ^ 0.6539 * NCSCIEquip ^ 0.4784
Lines of Code Control		KLOC	350.0 *	350
NCSI Control		NCSCI	3.0 *	3
Manmonths Control System (		MMControl	2,160.6 *	17.44 * KLOC ^ 0.8284 * NCSCI ^ (-0.03033)
Cost of Software Manmonth	3020	MM$	$ 10,130 *	10000
Antenna Aperture (sq ft)		Aper	200.0 *	200
Buy Quantity		BuyQty	75.0 *	FYISLIDE(DATEYR(EndR&DDate)+1)
Antenna Lrning Slope		Slp	90.0 *	90

- Hypothesize that Non-Recurring and "Other" costs are related to the software development.
- Note that Lines of Code Count drive the software costs
- Establish a 90% correlation amongst these items.

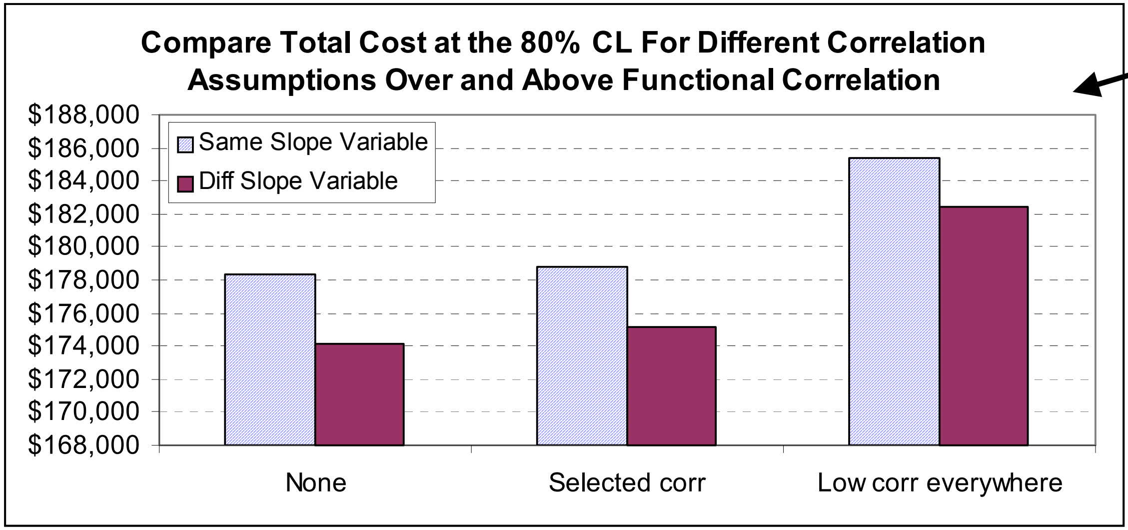
Before applying correlation.

WBS/CES	Row 42: RD Other	Row 46: Non Recurring	Row 52: Other	Row 59: Lines of Code Equip	Row 63: Lines of Code Control
RD Other	1.00	-0.01	-0.01	-0.00	-0.01
Non Recurring		1.00	-0.02	-0.01	0.01
Other			1.00	-0.01	-0.00
Lines of Code Equip				1.00	0.00
Lines of Code Control					1.00

After applying correlation.

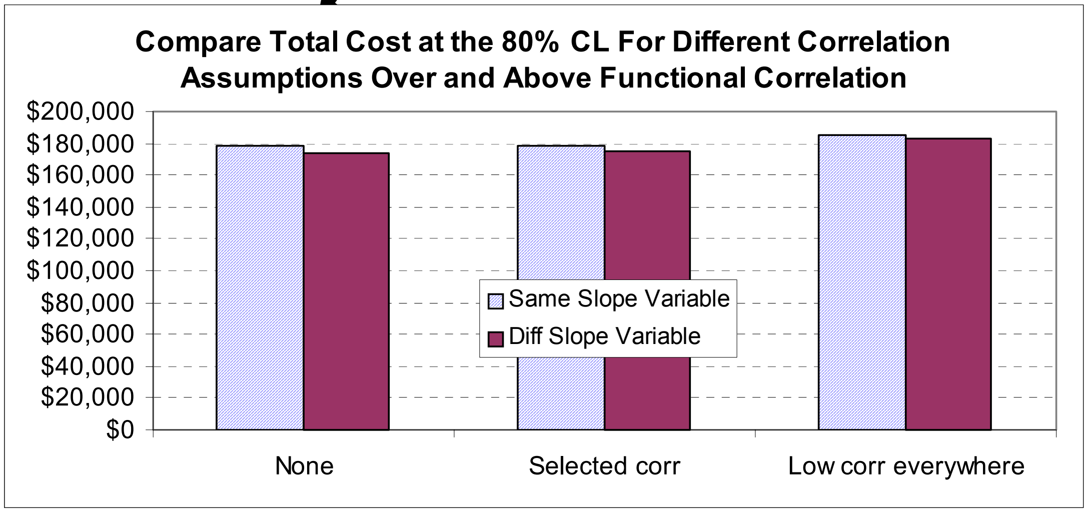
WBS/CES	Row 42: RD Other	Row 46: Non Recurring	Row 52: Other	Row 59: Lines of Code Equip	Row 63: Lines of Code Control
RD Other	1.00	0.89	0.88	0.88	0.88
Non Recurring		1.00	0.88	0.88	0.88
Other			1.00	0.90	0.90
Lines of Code Equip				1.00	0.90
Lines of Code Control					1.00

Functionally Correlated Risk



Use this scale if you wish to induce unnecessary alarm in the reader over the impact of your detailed comparisons.

Use this scale if you wish to show that agonizing over correlation issues may not be worth your time.



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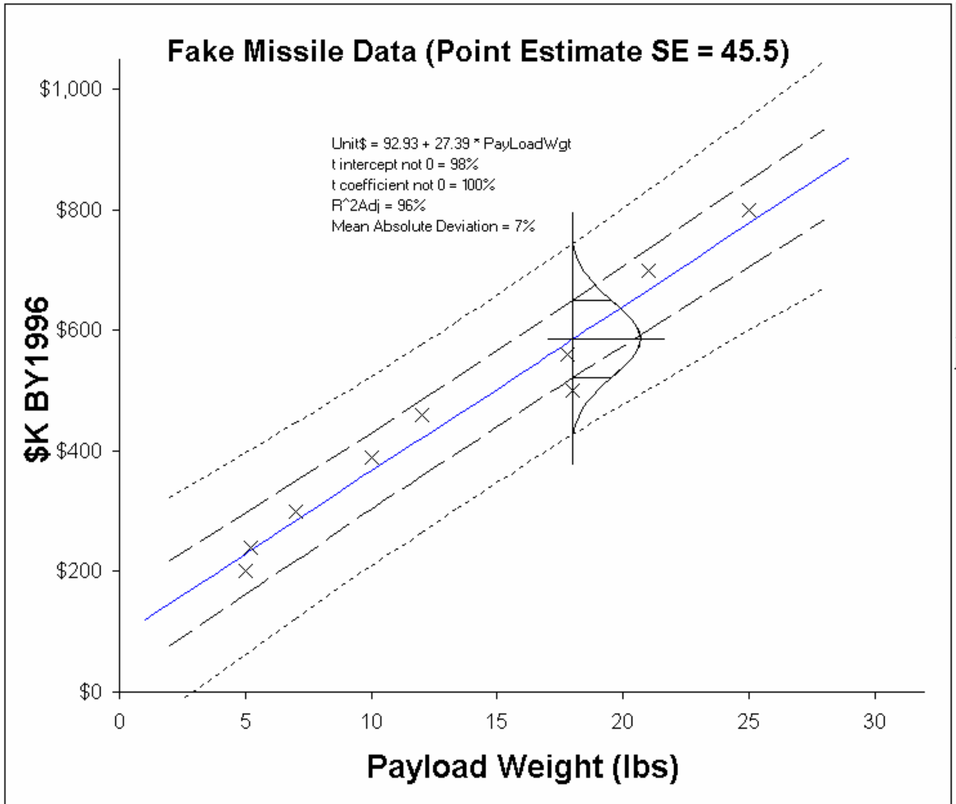
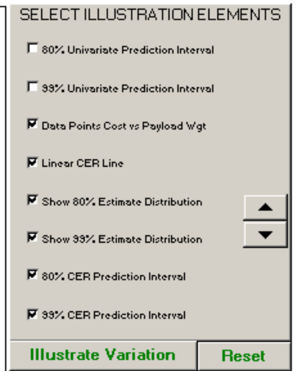
Accuracy of a CER





Standard Error of the Estimate = 42.2 = $\sqrt{\dfrac{\sum(y-\hat{y})^2}{n-k}}$

y = Data Point
$\hat{y}$ = Predicted Point
n = Number of DataPoints
k = Number of Coefficien ts

The further your point estimate is from the centroid of the sample data, the greater the error.

Unit$ = 92.93 + 27.39 * Wgt R^2Adj = 96% Mean Absolute Deviation = 7%	Lower Bound of Data	Mid Range of Data	Upper Bound of Data
Input Weight (lbs)	4	15	23
Confidence Level (%)	80%	80%	80%
Point Estimate Standard Error	**48.5**	**44.6**	**48.6**
Lower Bound	$134	$441	$654
Estimate	$202	$504	$723
Upper Bound	$271	$567	$792
	Bounds For RI$K		
Lower Bound	66%	87%	90%
Upper Bound	134%	113%	110%

Theoretical Basis for the ACE Correlation Method

- Pearson's Product Moment Correlation v.s. Spearman's Rank Order Correlation
- ACE uses the Pearson's definition to model correlations in risk simulations.

- Lurie-Goldberg's Simulation Method[1] is summarized in the paper.
- ACE uses a modified Lurie-Goldberg algorithm to create a set of variables that match the user-supplied correlations.

1. Simulating Correlated Random Variables; Philip M. Lurie and Matthew S. Goldberg; Institute for Defense Analyses; 32nd DODCAS; 2-5 February 1999

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Differences between ACE and Lurie-Goldberg

- ACE only allows the user to enter a single vector of correlation coefficients where the correlations are relative to the dominant cost driver in a particular "Group" of WBS elements. By doing this, the remaining members of the correlation matrix are "implied" (and therefore consistent) and the algorithm is simplified.
- ACE uses ranks during the simulation process to smooth out the resulting variables to make them suitable for the Latin-Hypercube (LH) simulation. Ranking in this context is for the purpose of <u>generating the LH draws</u> such that they closely resemble the original input distributions, and it should <u>not</u> be confused with <u>rank order correlation</u>.
- ACE does not iterate on the user supplied "Group Strengths" to achieve the desired correlations among the WBS elements. Nonetheless, in our test cases the user-defined group strengths match the desired correlations very closely, all within 0.5%.

Pearson's Product Moment Correlation

$$r = \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum (X - \bar{X})^2}\sqrt{\sum (Y - \bar{Y})^2}}$$

or

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\left(n\sum X^2 - \left(\sum X\right)^2\right) * \left(n\sum Y^2 - \left(\sum Y\right)^2\right)}}$$

n = number of ordered pairs

σ = standard deviation

μ = mean

X = first variable of an ordered pair

Y = second variable of an ordered pair

General Steps for the ACE/RI$K Algorithm

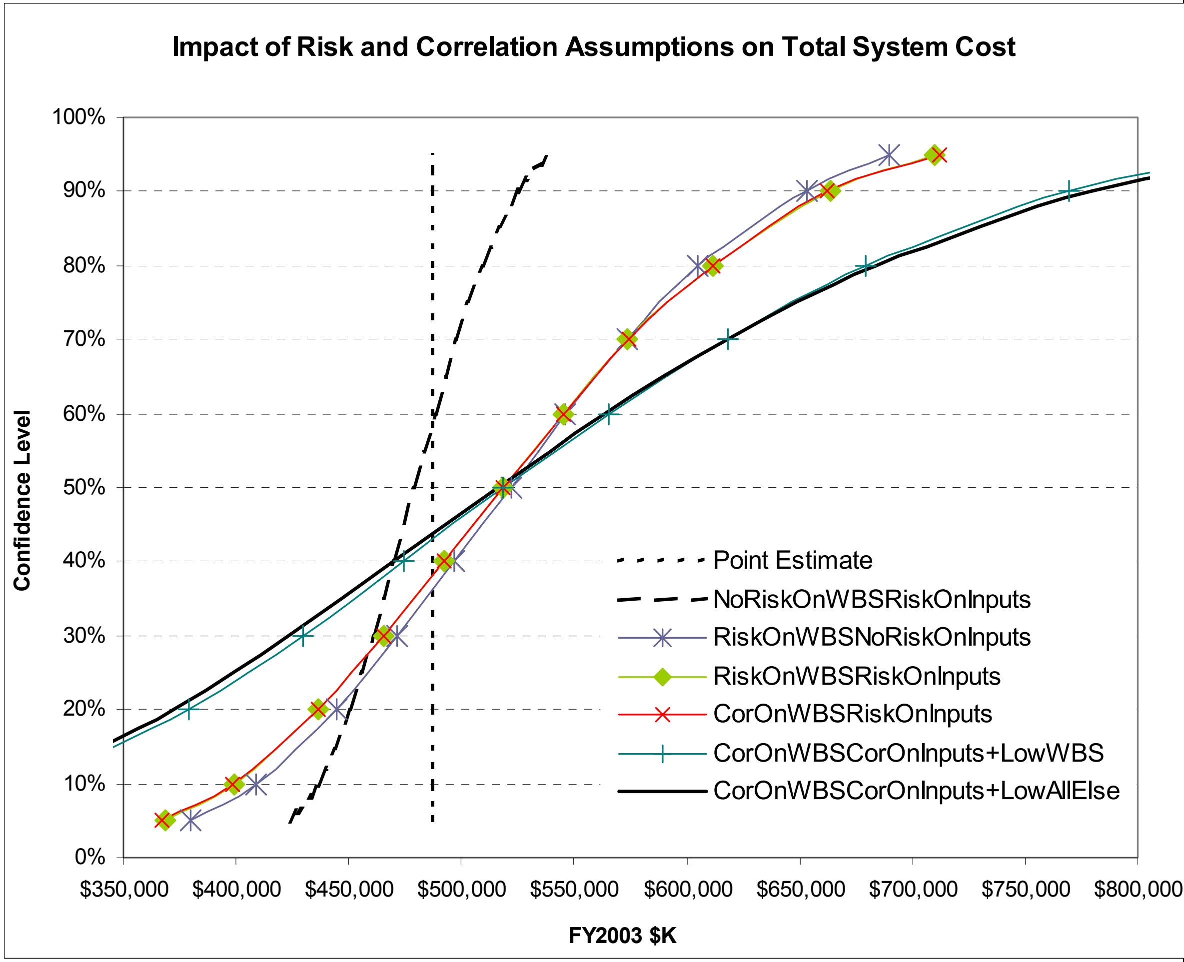
- Generate n independent draws, Z1, Z2, …Zn, from a standard normal distribution.
- Construct n correlated standard normal random variables X1, X2, … Xn using Cholesky's pairwise factorization formula.

$$
\begin{aligned}
X_1 &= Z_1 \\
X_2 &= \rho_2\, Z_1 + \sqrt{1-\rho_2^{\;2}}\; Z_2 \\
X_3 &= \rho_3\, Z_1 + \sqrt{1-\rho_3^{\;2}}\; Z_3 \\
&\ldots \\
X_n &= \rho_n\, Z_1 + \sqrt{1-\rho_n^{\;2}}\; Z_n
\end{aligned}
$$

- Generate the corresponding uniform LH draws for the Xi variables consistent with the value of the normal cumulative probability for each of the Xi values.
- Invert the uniform draws by the user-defined marginal distribution Fi:

$$Y_i = F_i^{-1}(U_i)$$

Impact on on Total Cost by Layering Risk Assumptions



In this model, the impact of correlating the Gimbal elements is insignificant. Applying 20% across all remaining WBS elements and inputs increases the cost result at 80% by 12%. The CoV of the final result is 35%.

Applying risk to the CERs and inputs in ACE, before layering correlation, captures most of the risk. Forcing a 20% correlation across all elements (other than the Gimbal) does have a significant impact in this model.

Although the CoV of the final result is 35%, it might be excessive. To force even a 20% correlation across all elements is contrary to correlation studies on some datasets.